Title: ON THE PROBLEM OF THE HIGH TEMPERATURE STRENGTH OF ALLOYS

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Source: Doklady Akademii Nauk SSSR, Novaya seriya, Vol LXXIII, No 2,1950,
pp 303-305

SECRET

ON THE PROBLEM OF THE HIGH TEMPERATURE STRENGTH OF ALLOYS

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Submitted 8 Dec 1949.

There are some attempts in recent technical literature to find the physical principles for obtaining heat-resistant alloys. K. Osipov [1], for example, after analyzing so-called N(E)-curves for alpha- and gamma-iron, explains the greater heat-resistance of gamma-solid solutions; and this explanation is in agreement with an experiment. His reasoning is as follows.

In comparing the N(E)-curves for alpha- and gamma-iron, it is noticed that the curve for alpha-iron is located higher than that for gamma-iron in a certain definite range of energies. During the formation of solid solutions from transitional elements the generalization of N(E)-curves takes place, and the resultant curve, basically, preserves the character of the initial N(E)-curves peculiar to either alpha- or gamma-iron, since this character is chiefly determined by the crystal symmetry and nature of the solvent.

If, for instance, the elements to be fused possess a gamma-lattice (addition of Ni to Fe), the generalized N(E)-curve will differ very little from the N(E)-curves of the components, and, during plastic deformation, external conditions will not produce any essential change in distribution and energy of electrons; the band will be predominantly of a metallic nature.

But if chromium, whose N(E)-curve is close to the curve for alpha-iron, is added to gamma-iron, electrons will mostly localize near the atoms of the solvent, considerably strengthening the bond, which in this case, is essentially different from a metallic bond.

In close connection to these conclusions are the data obtained by the author in his investigation of diffusion in certain alloys and the data on self-diffusion [2-4].

- 1 -

SECRET

SECRET

Analysis of these data (Table 1) shows that it is possible to assume -- with a sufficient degree of accuracy -- the energy of activation for self-diffusion E_a proportional to the energy of bonding E_b. For metals with a coordination number $z = 12$ the proportionality coefficient is $k \cong 0.65$, and for metals with $z = 6$, $k \cong 0.65$. Calculation of data on the investigation of diffusion in alpha-solid solutions Cu-Zn, Ag-Cd and Ag-Zn shows that the same relation exists between E_a and E_b in this case also.

Comparison of data for the energy of activation upon self-diffusion and the energy of activation for creep [5] at high temperatures demonstrates that these values coincide within the limits of experimental error (Table 2).

Table 1

Metal	E_a in kcal/g-at	E_b in kcal/g-at	$k = \dfrac{E_a}{E_b}$	Metal	E_a	E_b	$k = \dfrac{E_a}{E_b}$
Pb	27.65 [2]	47.5	0.58	Cu	51.0 [3]	81.2	0.62
Bi	29.95 [2]	47.8	0.63	Ag	46.6 [3]	68.0	0.68
Zn	17.28 [3]	27.4	0.63	Al	37.5 [3]	55.0	0.68
Au	51.0 [2]	92.0	0.56	γ-Fe	48.0 [4]	94.0	0.51
Au	62.9 [3]	92.0	0.68	α-Fe	78.0 [4]	94.0	0.83
Cu	57.2 [2]	81.0	0.70				

Table 2

Metal (alloy)	Zn	Cd	Bi	Al	Cu	Fe	Alpha-brass
E_a (self-diffusion) in kcal/g-at	17.6	17.8	30.0	37.5	57.2	78.2	41.7 [2]
E_c (for creep) in kcal/g-at	16.8	15.2	20.0	37.0	56.0	90.0	42.0

Since $E_a = kE_b$, it may be concluded that the near values of activation energies in what first appear to be different processes, show that, obviously, the mechanisms of these processes are of similar character, and also prove

- 2 -

SECRET

the possibility of considering the activation energy obtained for diffusion as a criterion for the heat resistance of a given alloy.

It should be noted that heat resistance is conditioned by many other factors which are difficult of consideration for the time being. On the other hand, the activation energy, obtainable from data on the investigation of diffusion, may be qualitatively related to the shape of $N(E)$ curves for metals or alloys. It should always be remembered that, with the same number of electrons per atom and the same coordination number for the metals to be compared, a lower bonding energy corresponds to a higher value of $N_{max}(E)$ and inversely. This may be illustrated by following examples.

The $N(E)$-curves for silver and copper, presented in Figure 1, show that $N_{max}(E)Cu < N_{max}(E)Ag$ (in the limits of the first Brilluen zone) and $E(Cu) > E(Ag)$. At the same time, the energy of activation for self-diffusion of copper is greater than that for silver (see Table 1).

Experiments demonstrated [6] that during the diffusion of molybdenum into alpha- and gamma-iron the energies of activation are similar in both cases and equal to ~58,500 cal/g-at, although the diffusion coefficients differ considerably.

The mechanism of diffusion is similar for both alpha- and gamma-solid solutions. But due to $k_{alpha} > k_{gamma}$, the bonding energy in the gamma-solid solution is greater than that for the alpha-solid solution at equal values of E_a. This is in agreement with the conception of the resonance of $N(E)$-curves (1).

Experiments for the diffusion of nickel into gamma-iron [7] and chromium into gamma-iron [8] showed that, in the first case $E_a = 67$ kcal/g-at, and in the second case $E_a = 112$ kcal/g-at. Density of states on the $N(E)$-curve for gamma-iron is lower than that for nickel near higher levels. Therefore, upon addition of 8-9% Ni to gamma-iron, the density of states will decrease somewhat and the bonding energy of the gamma-solid solution will grow.

- 3 -

Taking into consideration that the bonds in this case are predominantly of metallic character and accepting $k = 0.65$, we obtain for the bonding energy of the alloy a value ~100 kcal/g-at, which is greater than the value for the bonding energy of iron (94 kcal/g-at as indicated in Table 1).

An entirely different situation is observed in the case of diffusion of chromium ($z=6$) into gamma-iron. Chromium has an $N(E)$-curve near to that of alpha-iron. Addition of ~8% Cr to gamma-iron gives an insignificant resonance and, as a result, a great nonuniformity in the distribution of electrons is created, causing a considerable increase in the bonding energy of the gamma-solid solution and, consequently, an increase in the energy of activation during diffusion. This is corroborated by experiment [8].

The significance of the data obtained in the investigation of diffusion in alloys for clarification of the creep mechanism, is quite obvious.

Investigation of the process of self-diffusion and diffusion in alloys reveals that the most possible mechanism appears to be an occupation of vacant places in the lattice by diffusing atoms. If this is the case, the role of such vacant places must be considered in explaining the creep mechanism, remembering the factor of approximate equality of the energies of activation in diffusion and creep. The number of these vacant places depends on temperature.

The rate of the creep process will obviously depend on the rate of formation of vacancies and on the character of their distribution as well as on the rate at which they are filled with adjacent atoms. Consideration of these factors will permit clarification of the mechanism of creep.

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- 4 -

SECRET

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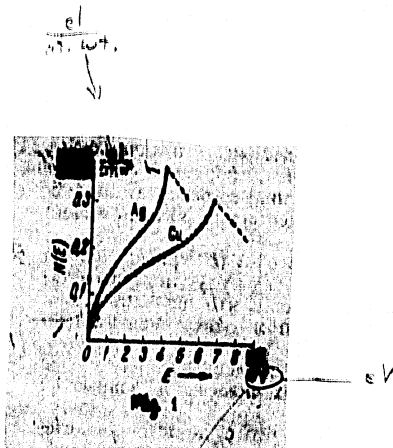
Figure I

- 5 -

SECRET